Specific Anosmia Observed for β -lonone, but not for α -lonone: Significance for Flavor Research

A. PLOTTO, K.W. BARNES, AND K.L. GOODNER

ABSTRACT: In the context of measuring thresholds of orange flavor compounds in a deodorized orange juice matrix, it was found that 50% of panelists could not perceive β -ionone or β -damascenone as well as the other panelists. Orthonasal and retronasal thresholds for β -ionone were, respectively, 985 and 490 times higher for nonperceivers than perceivers. For β -damascenone, the ratios were 690 and 390 times higher for ortho- and retronasal thresholds, respectively. Panelists who could not perceive β -ionone were otherwise good perceivers of most compounds tested. There were no such differences for α -ionone, a constitutional isomer of β -ionone. All 3 compounds were retested in water using the same panelists. Differences between nonperceivers and perceivers of β -ionone were 4900 and 4600 times higher for ortho- and retronasal thresholds for nonperceivers, respectively. However, for β -damascenone, no such differences were found when measured in water. The same panelists could be classified as "perceivers" or "nonperceivers" when β -ionone was tested in deodorized orange juice or in water. A different panel was used to confirm β -ionone and β -damascenone thresholds in water. A greater difference between perceivers and nonperceivers was found for β -ionone; as with the first panel, there were no differences in sensitivity to β -damascenone between panelists when the compound was tested in water.

Keywords: β -damascenone, orange juice, orthonasal, retronasal, threshold

Introduction

lpha-and β -ionone and β -damascenone are nor-isoprenoids $\mathbf{\Lambda}$ widely found in plants and plant products, as they are degradation products of carotenoids (Winterhalter and Rouseff 2002). They are usually considered as important flavor contributors in many fruit and fruit-based foods because they have low-odor thresholds (Cunningham and others 1986; Teranishi and Buttery 1987; Buttery and others 1989, 1990; Larsen and Poll 1990; Lopez and others 2004; Mahattanatawee and others 2005). These compounds are widely used by the flavor industry, hence their importance in foods. Annual volumes of α - and β -ionone used as flavoring agents in the 1970s in Europe were 2220 kg and 1100 kg, respectively, as reported by the International Organization of the Flavor Industry, yielding an estimated per capita intake of 310 and 150 $\mu \mathrm{g}$ per day, respectively (Anonymous 1999). In the United States, reported annual volumes use of α - and β -ionone in 1989 were 770 kg and 550 kg, respectively, with a per capita intake of 150 and 110 μ g per day, respectively (Anonymous 1999). In contrast, the per capita intake for β -damascenone was estimated to be 86 μ g per day in Europe and 5 μ g per day in the United States.

The USDA Citrus and Subtropical Laboratory has a long history of analyzing flavor compounds in citrus and citrus products (Coleman and Shaw 1970; Shaw 1977, 1991). In an ongoing study, thresholds of compounds found to be important in orange juice are being measured by using deodorized orange juice (pumpout) as a matrix, instead of water (Margaría and others 2002; Plotto and others 2004). By using the orange juice as the medium of evaluation instead of wa-

MS 20050734 Submitted 12/12/05, Accepted 4/2/06. Authors Plotto and Goodner are with U.S.D.A. – A.R.S., Citrus and Subtropical Products Laboratory, 600 Ave. S, NW, Winter Haven, FL 33881. Author Barnes is with Danisco USA Inc., 3919 Kidron Road, Lakeland, FL 33811-1293. Direct inquiries to author Plotto (E-mail: plotto@citrus.usda.gov).

ter, thresholds are deemed to be more realistic than in air or water, and values can be directly used by the citrus and flavor industry for standardization or quality control purposes. Also, information on the effect of the interactions of volatile compounds with the solute on sensory perception is gained. In that context, it was found that 50% of panelists could not perceive β -ionone or β -damascenone as well as the other panelists.

The term partial, or specific, anosmia is used when individuals who generally have a good sense of smell for most odors are much less sensitive to specific compounds by about one-hundredth of the average population (Amoore 1971). From experimental results, compiling literature or personal communications, Amoore (1969) published a list of 62 compounds among which 40 were found to present specific anosmia by at least 4% of the population tested. Specific anosmia, where at least 30% of the population tested was partially anosmic to a compound, was reported for isobutyraldehyde (Amoore and others 1976), geraniol (Amoore 1969), glutaraldehyde (Cain and Schmidt 2002), musk xylol (Amoore 1969), and 3,4,5,6,6pentamethyl-hept-3-en-2-one (Sulmont and others 2002). Although many compounds were observed to have some bimodal distribution of threshold levels, specific anosmia was not always confirmed due to lack of reproducibility of measurements (Lawless and others 1995). Also, variability of individual thresholds over time was found to be as large as threshold differences between two groups of panelists (Stevens and others 1988). One of the most known specific anosmia is that of androstenone (5-androst-16-en-3-one), for which 11% to 75% of the population is thought to be partially anosmic, although it was recently retested and the actual rate of nondetection appeared to be closer to 5% (Bremmer and others 2003).

This study was undertaken to confirm the β -ionone and β -damascenone threshold bimodal distributions in water. α -lonone was also tested for comparison with β -ionone. Thresholds in water were measured by using the same subjects for which data were previously obtained in orange juice, as well as by an additional panel.

Materials and Methods

Materials

Deodorized orange juice concentrate (termed "pumpout" by the industry) from Valencia oranges was provided by a Florida juice manufacturer. The pumpout was reconstituted to single-strength orange juice with purified drinking water (Deer Park, Greenwich, Conn., U.S.A.) to 11.8 \pm 0.1 $^{\circ}$ Brix. Analytical composition of the pumpout was reported previously (Plotto and others 2004). The sensory quality of reconstituted pumpout was assessed by a group of 4 experienced panelists and was described as bland, sweet, slightly tangy. In addition, insignificant odors were perceived from a pumpout extract analyzed by gas chromatography and olfactometry (GCO). When water (Deer Park, Greenwich, Conn., U.S.A.) was the medium of evaluation, ethanol 200 proof (Florida Distillers, Auburndale, Fla., U.S.A.) was used to take the compounds into solution.

Food grade α - and β -ionone was purchased from Sigma-Aldrich, Flavors and Fragrances (Milwaukee, Wis., U.S.A.), and β damascenone was provided by a flavor company. All 3 compounds were >99% pure by GC-MS. Olfactory purity was verified by GCO: the only impurities found in α - and β -ionone were from the β - and α -ionone isomers, respectively, and were insignificant at the concentrations tested. β -Damascenone was found to be pure at 99+% by GCO.

Sample preparation

Fresh reconstituted juice was prepared from frozen pumpout and stored at 4 °C for up to 5 d. One liter of juice was spiked with the aroma compounds at the highest concentration used in the taste panel (X), and refrigerated overnight at 4 °C to allow the compound to equilibrate with the juice (Shaw, unpublished data). Four successive 3-fold dilutions (X/3, X/9, X/27, X/81) were then prepared immediately before tasting. Fifteen milliliters of orange juice (control and spiked) were poured into 29.5 mL plastic (polystyrene) soufflé cups and capped (Solo® Cup Company, Urbana, Ill., U.S.A.). Control samples were prepared on the day before the panel and maintained at 4 °C overnight. Spiked samples were prepared right before the panel, and placed on the serving trays with the blanks in a cooler at 10 °C to 12 °C to equilibrate temperature with the control until served.

When tested in water, compounds were initially diluted in ethanol. Ethanol concentration in the blanks (not spiked) samples was adjusted to the level required to get the compound into solution. Therefore, blank samples were prepared with ethanol at 15 ppm for α -ionone, 1.5 and 5 ppm for β -damascenone, and 9 ppm and 500 ppm for β -ionone.

Taste panels

Nineteen to 22 volunteers participated in the sensory panels. Panel A consisted of panelists who have performed the same task for over 2 y. Most panelists participated in all tests; since there was a 6-mo interval between the tests in pumpout and in water for β ionone, and 1 y for β -damascenone and α -ionone, 3 new panelists were included in the later panels, while 2 had withdrawn. Panel A consisted of 50% male and 50% female, age ranging 26 to 55 y, with approximately 30% of each group 26 to 35 y, 36 to 45 y, and 46 to -55y. The panels took place in individual booths, usually from 10:00 AM to 12:00 PM (noon). Panel B were experts who were used to performing sensory evaluation tasks, but not this specific method. Age and gender distribution of panel B was similar to that of panel A.

The 3-alternative forced choice (3-AFC) test was used for threshold determination (ASTM Designation: E-679, 1997). In this method, the 3-AFC consists of 3 samples: 2 are controls and 1 is the spiked sample. Panelists were presented with a tray of 15 cups, corresponding to five 3-AFCs with 5 spiking levels; each level differed from the preceding by a factor of 3 (X/81, X/27, X/9, X/3, and X) and were tested in ascending order (most diluted first) and from left to right. All cups were labeled with a randomized 3-digit number. The order in which the spiked sample appeared for each level was randomized and balanced among subjects. Panelists were first instructed to uncap the cups near their nose, smell, and choose the spiked sample in each set of 3 cups. If they could not perceive a difference, they were instructed to guess (forced choice). Panelists then tasted the samples and again were asked to choose the spiked sample. The probability of randomly choosing the correct sample was 1 in 3. When they could perceive the spiked sample with certainty, panelists were asked to write an additional comment on the quality of the odor or taste. Sample temperature at serving was 10 $^{\circ}$ C to 12 $^{\circ}$ C for tests in pumpout to reproduce consumer conditions of drinking chilled orange juice, and it was 12 $^{\circ}$ C to 14 $^{\circ}$ C for tests in water. Each panel was repeated 4 times, and concentrations of spiked samples were adjusted until threshold was identified for all panelists.

Threshold determination

The best estimate criterion was used to calculate individual thresholds: the threshold for each individual at each panel was an interpolated value calculated by taking the geometric mean between the last concentration missed and the first concentration detected. The panelists' individual best estimate threshold (BET) was the geometric mean of all the session thresholds, and the group (population) threshold was obtained by a geometric mean of the individual BETs for each compound.

Results

or panel A, individual orthonasal thresholds in water ranged $oldsymbol{\Gamma}$ from 0.11 to 2532 ppb, 0.94 to 52.67 ppb, and 0.001 to 1.25 ppb for β -ionone, α -ionone, and β -damascenone, respectively. The ranges were 1.08 to 16570 ppb, 18.6 to 289 ppb, and 0.012 to 4235 ppb for the same compounds in pumpout. For the same compounds, individual retronasal thresholds ranged from 0.05 to 1462 ppb, 0.31 to 8.44 ppb, and 0.001 to 1.25 ppb in water, and from 0.82 to 2655 ppb, 6 to 42 ppb, and 0.012 to 152 ppb in pumpout. For panel B, which consisted of experts not as used to performing the required task, even wider ranges were observed for β -ionone in water: 0.006 to 3480 ppb, and 0.006 to 2413 ppb orthonasally and retronasally, respectively. β-Damascenone thresholds for panel B ranged from 0.0007 to 0.508 ppb orthonasally and from 0.003 to 0.487 ppb retronasally. Figure 1 shows the frequency distribution of all measured orthonasal thresholds of panel A for all panel sessions compounded. The distributions appear bimodal for β -ionone in water and pumpout, and for β -damascenone in pumpout but not in water, while it is normal for α -ionone in both pumpout and water. For the remainder of the discussion, panelists under the right- and left-hand side of the bell-shape curve are defined as "perceivers" and "nonperceivers," respectively.

Beta-Ionone

A closer look at the mean thresholds reveals that thresholds were 985- and 490-fold higher for nonperceivers than for perceivers for β ionone in pumpout for panel A (Table 1), while there was no such difference for α -ionone (Figure 1; Table 3). The test was repeated 6 mo later using the same method and the same panelists except 3, but the medium of evaluation was water. Larger differences were found between perceivers and nonperceivers, with nonperceivers having a threshold over 4900-fold larger than perceivers (Table 1). Panelist variability, reported for other compounds over time (Stevens and others 1988; Lawless and others 1995), was therefore not observed for β -ionone, and classification of panelists between "perceivers" and "nonperceivers" was confirmed. Also, the definition of specific anosmia (Amoore 1971, 1991) was confirmed in this test since panelists, otherwise classified as good perceivers for most compounds tested (about 30 at the time β -ionone was tested, including terpenes, aldehydes (Plotto and others 2004), and esters [unpublished data]).

could not smell or taste β -ionone. To further confirm this observation, the test protocol was repeated by using a second panel, briefly trained for the task. An even wider difference between perceivers and nonperceivers was observed (Table 1). In each panel (panel A, pumpout; panel A, water; panel B, water), the distribution between perceivers and nonperceivers was about 50%.

Panelists in panel A were requested to give a descriptor, based on personal experience, if they could identify the flavor at a certain concentration level. Perceivers of β -ionone were more consistent in the descriptors they chose, mostly fruity and berry-like, or floral and perfumey or soapy (Table 2). On the other hand, nonperceivers used a wider vocabulary, including plastic, chemical, musty, and

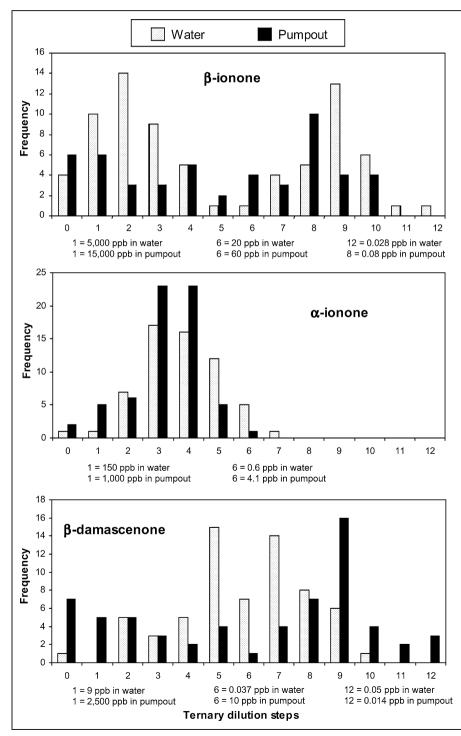


Figure 1 — Frequency distribution of β -ionone, α -ionone, and β -damascenone orthonasal thresholds for panel A measured in water and deodorized orange juice (pumpout). Data are results of 4 ascending trials (not averaged), rounded to the nearest concentration steps. Concentrations in water or pumpout for steps 1, 6, and 12 are indicated below each compound, accordingly.

Table 1 — Detection thresholds (μ g/L) and log standard deviations (in parenthesis) for β -ionone tested in deodorized orange juice (pumpout) or water, by two separate panels, and published values for comparison

	Perceivers (P)		Nonperceivers (NP)		Ratio NP/P		All panelists means		Published in water	
Medium of evaluation	Ortho- nasal	Retro- nasal	Ortho- nasal	Retro- nasal	Ortho- nasal	Retro- nasal	Ortho- nasal	Retro- nasal	Ortho- nasal	Retro- nasal
Pumpout (Panel A)	2.67 (0.37)	1.92 (0.30)	2630 (0.64)	941 (0.48)	985	490	72.2 (1.61)	39.0 (1.42)		
Water (Panel A)	0.168 (0.16)	0.104 (0.28)	823 (0.42)	474 0.35)	4900	4560	18.0 (1.94)	`8.78 [′] (1.90)	0.007 ^a 0.03 ^b	
Water (Panel B)	0.135 (0.62)	0.0579 (0.56)	1310 (0.55)	605 [°] (0.59)	9710	10400	`8.82 [′] (0.79)	4.39 (0.75)	0.5° 23 ^d	

^aButtery and others (1990)

cleaning agent. This confirms that some nonperceivers can have a different experience than perceivers from smelling or tasting β -ionone.

Alpha-Ionone

As illustrated in Figure 1, thresholds for α -ionone followed a normal distribution, in both pumpout and water. Because its threshold is higher than for its isomer β -ionone, α -ionone is less frequently cited as having a flavor impact or being important for foods. In our study with panel A in water, α -ionone threshold is about 20 times higher than for its isomer β -ionone (Table 3 compared with Table 1—"perceivers"). Although panelists gave similar descriptors to β -ionone and α -ionone, the latter has additionally a licorice-type note. The difference between β -ionone and α -ionone in terms of distribution of panelists perception levels may indicate that the receptor protein might be different for α - than for β -ionone, and it might vary more between individuals for the latter.

Beta-Damascenone

When tested in pumpout, about 50% of panelists could not perceive β -damascenone, and thresholds for nonperceivers were 692 and 387 times higher than those for perceivers, orthonasally and retronasally, respectively (Table 4). The ratios between nonperceiver and perceiver thresholds were within the same order of magnitude as for β -ionone. However, unlike β -ionone where panelists otherwise sensitive to flavor compounds were classified as nonperceivers, the nonperceivers for β -damascenone in pumpout tended to be panelists older than 45 y, which tended—but not always—to have higher thresholds for other compounds tested in pumpout in our ongoing study. When the test was repeated by using water as the medium of evaluation, the threshold differences between perceivers and nonperceivers was reduced to 16- and 52-fold for orthonasal and retronasal thresholds, respectively (Table 4). Similar threshold ratios were observed for panel B, where threshold differences between perceivers and nonperceivers were only 11-fold. Threshold values in water for perceivers were in agreement with published values, which implies that in most published thresh-

old studies, panelists are selected for sensitivity. If the average of all panelists was considered (Table 4), β -damascenone thresholds would be about 10 times higher in our study than for published values. β -Damascenone imparted mostly fruity notes to pumpout as described by perceivers, but nonpeceivers had a more limited vocabulary to describe the pumpout spiked with β -damascenone (Table 5). In water, β -damascenone also added an astringent mouthfeel (Table 5). Nonperceivers did not mention any descriptor when tested in water.

Discussion

 ${f B}$ eta-ionone partial anosmia was reported by Amoore (1969) in an informal test where 1 panelist out of 12 was anosmic to the compound in air. Buttery and others (1997) also reported 25% of their panel to be partially anosmic, but no threshold values were given for the anosmic subjects.

Published orthonasal thresholds for β -ionone in water are given in Table 1 for comparison and were 0.007 ppb (Buttery and others 1990), 0.03 ppb (Buttery and others 1997), 0.5 ppb (Larsen and Poll 1990), and 23 ppb (Tandon and others 2000). The lower thresholds published by Buttery's group can be attributed to highly trained panelists, which are selected for their sensitivity and reproducibility, and the mode of presenting the samples directly to the nostril by using squeeze bottles (Guadagni and others 1963; Buttery and others 1971). The higher threshold published by Larsen and Poll may be due to sample presentation with higher dilution steps at 1:10, therefore making the test less sensitive, but it is still comparable to the value found in our study. We chose in our study a dilution factor of 3, as it was found to be the best compromise to cover the range of concentrations that might be perceived by all panelists. The much higher value found by Tandon and and others (2000) would indicate that their panel comprised both sensitive and non-sensitive subjects, as the value of 23 ppb is closer to the mean of all panelists (18 ppb) in our study (Table 1). The standard deviations were not provided in any study (Buttery and others 1990, 1997; Tandon and others 2000); therefore, no firm inference can be drawn as to the composition of the panels in respect to subjects' sensitivity. Orthonasal thresholds in water for α -ionone were closer to the value published by Larsen

Table 2 — Identification thresholds (μ g/L), log standard deviations (in parenthesis), and descriptors for eta-ionone tested by panel A in deodorized orange juice (pumpout) or water

	Perceivers (P)			Nonperceivers (NP)				Ratio NP/P	
Medium of evaluation	Ortho- nasal	Retro- nasal	Descriptors	Ortho- nasal	Retro- nasal	Descriptors	Ortho- nasal	Retro- nasal	
Pumpout	16.5 (0.59)	8.89 (0.51)	floral, berries, soapy perfumey	2250 (0.55)	2410 (0.34)	floral, fruity, sweet, soapy perfumey, musty, cleaner, plastic	136	271	
Water	0.521 (0.52)	0.461 (0.52)	floral, grape, sweet, soapy perfumey	1780 (0.36)	1080 (0.46)	floral, fruity, soapy, herbal, plastic chemical	3420	2340	

^bButtery and others (1997)

cLarsen and Poll (1990). dTandon and others (2000).

Table 3-Detection and identification thresholds (μ g/L), log standard deviations (in parenthesis), and descriptors for α-ionone tested by panel A in deodorized orange juice (pumpout) or water, and published values in water for comparison

Medium of evaluation	Detection	thresholds		Identific	Published		
	Orthonasal	Retronasal	Orthonasal	Retronasal	Descriptors	Orthonasal	Retronasal
Pumpout	43.3 (0.35)	15.3 (0.22)	95.6 (0.33)	35.7 (0.36)	fruity, sweet, berries, cherry, floral, soapy, plastic, perfumey, candy		_
Water	3.78 (0.47)	1.64 (0.34)	10.6 (0.32)	5.67 (0.53)	floral (rose, violet), sweet, licorice soapy, perfumey, cherry	0.4ª 5 ^b	

^aTeranishi and Buttery (1987). ^bLarsen and Poll (1990).

Table 4 – Detection thresholds (μ g/L) and log standard deviations (in parenthesis) for β -damascenone tested in deodorized orange juice (pumpout) or water, by two separate panels, and published values for comparison

Medium of evaluation	Perceivers (P)		Nonperc	Nonperceivers (NP)		Ratio NP/P		All panelists means		Published in water	
	Ortho- nasal	Retro- nasal	Ortho- nasal	Retro- nasal	Ortho- nasal	Retro- nasal	Ortho- nasal	Retro- nasal	Ortho- nasal	Retro- nasal	
Pumpout (Panel A)	0.282 (0.89)	0.159 (0.77)	195 (0.75)	61.0 (0.37)	692	387	4.43 (1.65)	1.95 (1.45)			
Water (Panel A)	0.00834 (0.47)	0.00252	0.130 (0.58)	0.131 (0.75)	15.6	52.0	0.0237	0.0114	0.002ª	0.009°	
Water (Panel B)	0.00358 (0.56)	0.00142 (0.31)	0.0382 (0.55)	0.0149 (0.54)	10.7	10.5	0.0148 (0.79)	0.00642 (0.77)	0.00075⁵	0.001 ^d	

^aButtery and others (1990)

and Poll (5 ppb; 1990) than by Teranishi and Buttery (0.4 ppb; 1987) (Table 3). And finally, perceivers' orthonasal and retronasal thresholds for β -damascenone were in agreement with published values by Buttery and others (0.002 ppb; 1989) and Guth and Grosch (0.0012 ppb; 1993), respectively (Table 4).

For β -ionone, while thresholds in water for the perceivers were somewhat in agreement with published thresholds, the average of all thresholds, perceivers and nonperceivers, would raise the threshold by 100-fold (see all panelists averaged, Table 1). This would have significant impact in flavor research, where thresholds are widely used to identify compounds contributing to food flavor or aroma: when the concentration of a given compound in a food is higher than its threshold, that compound is deemed to contribute significantly to that food flavor. Therefore, considering the differences of thresholds between sensitive and nonsensitive subjects in our study, flavor perception of foods containing β -ionone may be quite different to nonperceivers than perceivers.

For example, β -ionone concentration in fresh tomato and tomato paste, 4 and 2 ppb respectively, was over 200-fold higher than its odor threshold, 0.007 ppb (Buttery and others 1989, 1990). The resulting log odor units (logarithm of the ratio of concentration found in the food to the threshold concentration) for β -ionone were 2.5 and 2.8 in tomato paste and fresh tomato, respectively, indicating the strong relative importance of that compound in tomato products. However, since sensitive and highly trained panelists generated thresholds in that study, threshold values were low, and hence the odor unit was

high. In the study by Tandon and others (2000) where β -ionone threshold was 23 ppb, the log odor unit of β -ionone was found to be negative by using volatile concentration of 4 ppb published by Buttery and others (1989) in the calculation of the odor unit, indicating the low contribution of β -ionone to tomato aroma. This large range of published threshold values shows that one must be careful in interpreting food flavor data and pay attention to sensory methodology and panelists selection.

Beta-ionone has a characteristic odor of violet. It was found to contribute 22% of the "floral" compounds in orange juice analyzed by GCO (Mahattanatawee and others 2005). When spiked to orange juice pumpout, β -ionone generated a "berry-like" descriptor among the perceivers, in addition to comments of floral, and perfumey (Table 2). When spiked into tomato homogenate, it generated descriptors of "floral" and "sweet" (Tandon and others 2000), or "tropical" and "floral" aroma, and "bitter" taste (Baldwin and others 2004), and it increased the sweetness of tomato homogenate (Baldwin and others 2004). In both panels (Tandon and others 2000; Baldwin and others 2004), interactions between β -ionone and nonvolatile compounds in the tomato homogenate changed the perception of β ionone. Beta-ionone also contributes to raspberry aroma, where its concentration, 550 to 2320 ppb (Larsen and Poll 1990), is well above any thresholds values (Table 1).

Beta-damascenone is generally described as "sweet," "honeylike," "tobacco," "grape juice," "prune" (Rychlik and others 1998), and all these descriptors were generated by perceivers in panel A

Table 5 – Identification thresholds (μ g/L), log standard deviations (in parenthesis), and descriptors for β -damascenone tested by panel A in deodorized orange juice (pumpout) or water

	Perceivers (P)				Nonpe	Ratio NP/P		
Medium of evaluation	Ortho- nasal	Retro- nasal	Descriptors	Ortho- nasal	Retro- nasal	Descriptors	Ortho- nasal	Retro- nasal
Pumpout	0.638 (0.47)	1.081 (0.85)	grape, fruity, sweet, molasses, prune apple candy, tobacco, honey	153 (1.50)	418 (0.72)	floral, tobacco, musty sweet	240	387
Water	0.0113 (0.40)	0.00495 (0.59)	fruity, floral, sweet, honey, perfumey astringent (taste)	` _ ′	` _ ′	no descriptors		

^bSemmelroch and others (1995).

[°]Ohloff (1978)

dGuth and Grosch (1993).

(Table 5). Beta-damascenone contributed to 19% of the "floral" compounds in orange juice analyzed by GCO (Mahattanatawee and others 2005). Its concentration ranged from 0.122 to 0.281 μ g/L in orange juice not from concentrate, and as high as 0.145 to 0.690 μ g/L in reconstituted orange juice from concentrate (Mahattanatawee and others 2004). These concentrations suggest that perceivers of β -damascenone would smell (orthonasal) and taste (by retronasal) olfaction) the compound when drinking orange juice. However, in pumpout, β -damascenone contributed a fruity flavor rather than floral, as found in water (Table 5) or in air by GCO (Mahattanatawee and others 2005). In another study, when β -damascenone, which had the second highest odor activity value by GCO, was omitted from a model mixture reconstituting Grenache wine, the intensity of the aroma model was only slightly decreased (Grosch 2001; Ferreira and others 2002), indicating β -damascenone is not a character impact compound, but probably contributes a sweet background note. Ferreira and others (2002) qualified β -damascenone as an "aroma enhancer." The fact that a bimodal distribution was found only when β -damascenone was tested in pumpout (Table 4) may indicate that because of the sweet background already present in the pumpout, half of the panelists could not differentiate the compound odor from the background. In fact, as noted earlier, most of "nonperceivers" for β -damascenone in pumpout were older than 45 y; this corresponds to the findings that loss of sensitivity with age includes loss of ability to discriminate odors (Leffingwell and Leffingwell 1991). Since the bimodal distribution was not found when β -damascenone was tested in water, and thresholds for "perceivers" were only 10- to 50fold lower than for "nonperceivers," it is concluded that one cannot talk about specific anosmia for β -damascenone. The differences between low and high thresholds for β -damascenone in pumpout gave additional information on volatile-matrix interaction, the response to that stimulus being processed at the cognition level in that case.

Odor thresholds are of great practical value to flavorists: published thresholds are used as a reference when the relative contribution of a compound needs to be known, as mentioned in the tomato examples above, but also when a flavor needs to be re-created from a known, usually natural source (Leffingwell and Leffingwell 1991). The specific anosmia found in 50% of the panelists tested for β -ionone shows that if nonperceivers' thresholds were used to reconstruct a flavor, the resulting flavor would be distorted, possibly objectionable to perceivers. Therefore, great care should be used when using published thresholds by verifying the methodology to obtain them.

References

- Amoore JE. 1969. A plan to identify most of the primary odors. In: Pfaff-Mann C, editor. Olfaction and taste III. New York: Rockefeller University Press. p 158-71
- Amoore JE. 1971. Olfactory genetics and anosmia. In: Beidler L, editor, Handbook sensory physiology Vol 4, pt 1. Berlin: Springer-Verlag. p 245-56. Amoore JE. 1991. Specific anosmias. In: Getchell TV, and others, editors. Smell and
- taste in health and disease. New York: Raven Press. p 655–64. Amoore JE, Forrester LJ, Pelosi P. 1976. Specific anosmia to isobutyraldehyde: the malty
- primary odor. Chem Senses Flavour 2(1):17-25.
- Anonymous. 1999. Safety evaluation of certain food additives. Ionones and structurally related food substances, WHO Food Additives Series 42:335-52.
- [ASTM] American Society for Testing and Materials. 1997. Standard Practice Designation E. Determination of odor and taste thresholds by a forced-choice ascending concentration series method of limits. Philadelphia: ASTM. p 679-91.

- Baldwin EA, Goodner KL, Plotto A, Pritchett K, Einstein M, 2004. Effect of volatiles and their concentration on perception of tomato descriptors. I Food Sci 69(8):S310-8.
- Bremmer EA, Mainland JD, Khan R, Sobel N. 2003. The prevalence of androstenone anosmia, Chem Senses 28:423-32
- Buttery RG, Seifert RM, Guadagni DG, Ling LC. 1971. Characterization of additional
- volatile components of tomato. J Agric Food Chem 19:524–9. Buttery RG, Teranishi R, Flath RA, Ling LC. 1989. Fresh tomato volatiles. Composition and sensory studies. In: Teranishi R. Buttery RG. Shahidi F. editors. Flavor chemistry: trends and developments. Washington, D.C.: ACS Symposium Series. p 213-22.
- Buttery RG, Teranishi R, Ling LC, Turnbaugh JG. 1990. Quantitative and sensory studies on tomato paste volatiles. J Agric Food Chem 38:336-40.
- Buttery RG, Ling LC, Stern DJ. 1997. Studies on popcorn aroma and flavor volatiles. J Agric Food Chem 45:837-43.
- Cain WS, Schmidt R. 2002. Sensory detection of glutaraldehyde in drinking water -Emergence of sensitivity and specific anosmia. Chem Senses 27:425-33.
- Coleman RL, Shaw PE. 1970. Analysis of Valencia orange essence and aroma oils. J Agric Food Chem 19:520-3.
- Cunningham DG, Acree TA, Barnard J, Butts RM, Braell PA. 1986. Charm analysis of apple volatiles. Food Chem 19:137-47.
- Ferreira V, Ortin N, Escudero A, Lopez R, Cacho J. 2002. Chemical characterization of the aroma of Grenache rose wines: aroma extract dilution analysis, quantitative determination, and sensory reconstitution studies. I Agric Food Chem 50:4048-54.
- Grosch W. 2001. Evaluation of the key odorants of foods by dilution experiments, aroma models and omission. Chem Senses 26:533-45.
- Guadagni DG, Buttery RG, Okano S. 1963. Odour thresholds of some organic compounds associated with food flavours. J Sci Food Agric 14:761-5.
- Guth H, Grosch W. 1993. Furanoid fatty acids as precursors of a key aroma compound of green tea. In: Schreier P, Winterhalter P, editors. Progress in flavour precursor studies. Carol Stream, IL: Allured Publishing. p 401-7
- Larsen M, Poll L. 1990. Odour thresholds of some important aroma compounds in raspberries, Z Lebensm Unters Forsch 191:129-31
- awless HT, Corrigan-Thomas CJ, Johnston M. 1995. Variation in odor thresholds for l-carvone and cineole and correlations with suprathreshold intensity ratings. Chem Senses 20:9-17.
- Leffingwell JC, Leffingwell D. 1991. GRAS flavor chemicals detection thresholds. Perfumer Flavorist 16(1):1-19.
- Lopez R, Ezpeleta E, Sanchez I, Cacho J, Ferreira V. 2004. Analysis of the aroma intensities of volatile compounds released from mild acid hydrolysates of odourless precursors extracted from Tempranillo and Grenache grapes using gas chromatographyolfactometry, Food Chem 88:95–103.
- Mahattanatawee K, Rouseff RL, Goodner KL. 2004. Determination of β -damascenone, a potent norisoprenoid aroma compound, in orange juice. Fifty-fifth Citrus Processors' and Subtropical Technology Conference, October 21, 2004. Lake Alfred, FL: IFAS, Abstract,
- Mahattanatawee K. Rouseff RL, Valim FM, Naim M, 2005, Identification and aroma impact of norisoprenoids in orange juice, I Agric Food Chem 53:393-7
- Margaría CA, Goodner KL, Goodrich RM, Baldwin EA. 2002. Detection and identification for key flavor components in an orange juice matrix. Proc Fla State Hort Soc
- Ohloff G. 1978. Importance of minor components in flavors and fragrances. Perfumer Flavorist 3:11-22
- Plotto A. Margaría CA. Goodner KL. Goodrich R. Baldwin EA. 2004. Odour and flavour thresholds for key aroma components in an orange juice matrix: terpenes and aldehydes. Flavour Fragrance J 19:491-8.
- Rychlik M, Schieberle P, Grosch W. 1998. Compilation of odor thresholds, odor qualities and retention indices of key food odorants. Garching, Germany: Deutsche Forschungsanstalt für Lebensmittelchemie and Institut für Lebensmittelchemie der Technischen Universität München. p 63.
- Semmelroch P, Laskawy G, Blank I, Grosch W. 1995. Determination of potent odorants in roasted coffee by stable isotope dilution assays. Flavour Fragrance J 10:1-7
- Shaw PE. 1977. Essential oils. In: Nagy S, Shaw PE, Veldhuis MK, editors. Citrus science and technology Vol. 1. Westport, Conn: Avi Publishing Co. p 427-62.
- Shaw PE. 1991. Fruits II. In: Maarse H, editor. Volatile compounds in foods and beverages. New York: Marcel Dekker. p 305-27
- Stevens JC, Cain WS, Burke RJ. 1988. Variability of olfactory thresholds. Chem Senses 13:643-53.
- Sulmont C, Issanchou S, Köster EP. 2002. Selection of odorants for memory tests on the basis of familiarity, perceived complexity, pleasantness, similarity and identification. Chem Senses 27:307-17.
- Tandon KS, Baldwin EA, Shewfelt RL. 2000. Aroma perception of individual volatile compounds in fresh tomatoes (Lycopersicon esculentum Mill.) as affected by the medium of evaluation. Postharvest Biol Technol 20:261-8.
- Teranishi R, Buttery RG. 1987. The significance of low threshold odor compounds in aroma research. In: Martens M, Dalen GA, Russwurm Jr H, editors. Flavour science and technology. New York: Wiley. p 513-27
- Vinterhalter P, Rouseff RL. 2002. Carotenoid-derived aroma compounds: an introduction. In: Winterhalter P, Rouseff RL, editors. Carotenoid-derived aroma compounds. Washington, DC: ACS Symposium Series 802. p 1-17.